MI/RR Space Charge Simulations with Synergia

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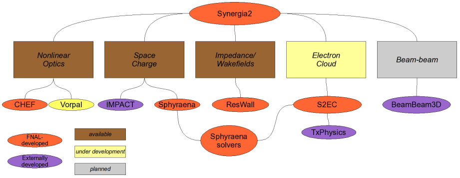
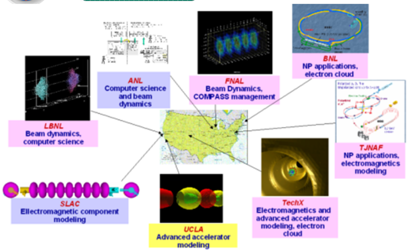
Project X Collaboration Meeting

Outline

Overview



https://compass.fnal.gov/

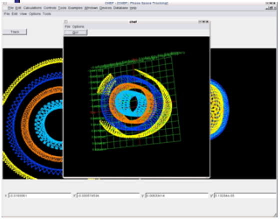


- Fully 3D PIC code
- Space charge included via split-operator technique
- Single-particle physics from CHEF
- Runs on desktops, clusters and supercomputers
- Fully dynamic simulations including ramping, feedback, etc.

- ComPASS collaboration includes most major accelerator simulation packages in the U.S., including all national labs
- Emphasis is on massively parallel computing

CHEF

Collaborative Hierarchical Expandable Framework



- CHEF originally developed at Fermilab by Leo Michelotti starting in the early 90's
- Single-particle optics with full dynamics
  - Can be reduced to arbitrary-order maps
  - We have done demonstration calculations in Synergia to 15^{th} order
- Customizable propagators
- MAD input
  - Internal representation not limited by MAD parameters

Space Charge and Resistive Wall Impedance

Space Charge

- Fully 3D space charge
  - Various boundary conditions: open, longitudinally periodic, conducting pipes
  - Utilizes (requires) large parallel computing resources
  - Extensively benchmarked against other codes
- 2D space charge
  - Useful in some limits, very fast

Resistive Wall Impedance

- Both intra-bunch and inter-bunch effects available
- Dipole and quadrupole effects implemented
- Benchmarked against theoretical values in various limits

Multibunch Physics

Multibunch Physics

- Synergia can model multiple interacting bunches
- Strongly-coupled bunches
  - Space charge calculations include all bunches on a single grid
  - Scales to a few bunches
  - Example: 400 MHz bunch merging in the Fermilab Booster
- Weakly-coupled bunches
  - Bunches only communicate through resistive wall effects
  - Scales to many bunches

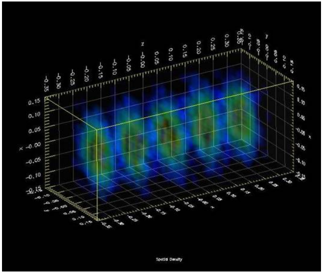
Additions for Project X

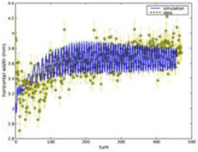
Complex apertures

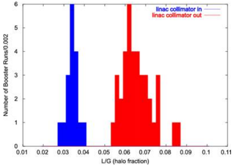
- Currently a single aperture is defined for the entire machine
  - We will add the ability to specify apertures on an element-by-element basis
- Only circular apertures are currently implemented
  - We will add other shapes as necessary

We have done extensive modeling of the Booster with Synergia

- 400 MHz structure debunching
- 37.7 MHz capture
  - Including RF phase ramping
- Emittance growth
  - Including comparison with experiment
- Halo formation
  - Including comparison with experiment







Mu2e

We are currently working on space charge simulations of the Fermilab Debuncher for the proposed Mu2e experiment

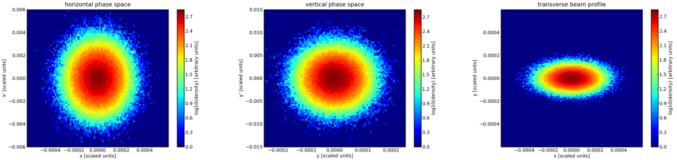
- Beam to be extracted from Debuncher using resonant extraction
- Accumulator/Debuncher required to handle 10^5 times more particles than current operating conditions

Beam parameters from proposal

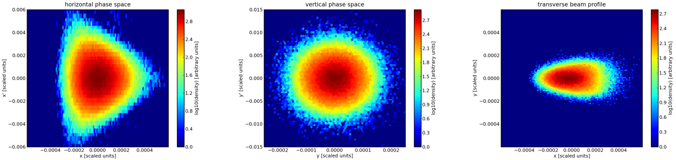
- 8 GeV
- 1.2×10^{13} protons/bunch
    - lower intensity bunches under consideration
- 20π emittance
- 40 nsec longitudinal RMS
- (Laslett) space charge tune shift is ~ 0.08

Mu2e Sextupole Ramping without Space Charge

Initial beam

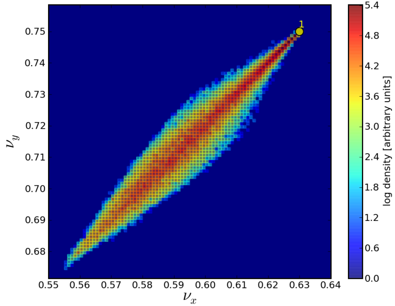


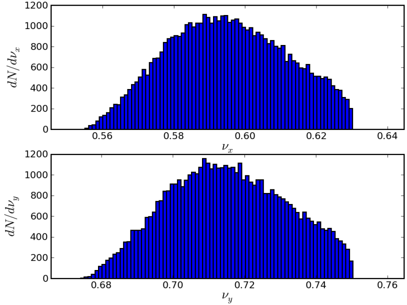
Final beam



Mu2e Space Charge without Sextupole Ramping

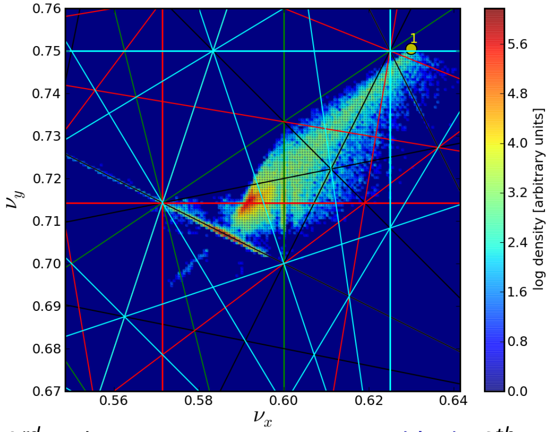
Bare tune: 0.63 horizontal, 0.75 vertical (Point 1)
Tune footprint:





- Two-dimensional densities (colors) are plotted on a logarithmic scale
- One-dimensional densities are plotted on a linear scale
- Bin sizes are one unit of tune resolution

Mu2e Sextupoles and Space Charge Combined



white 3^{rd}-order

orange 4^{th}-order

green 5^{th}-order

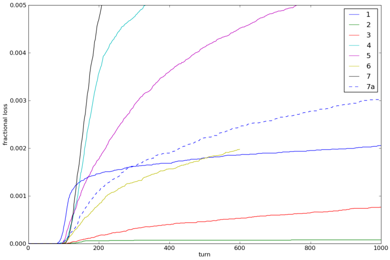
black 6^{th}-order

red 7^{th}-order

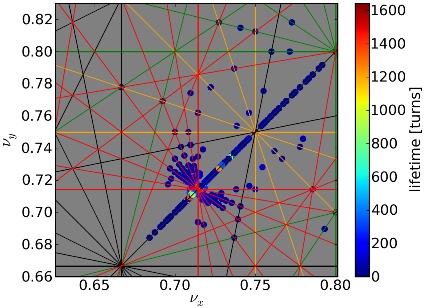
cyan 8^{th}-order

Mu2e loss analysis

We have studies aggregate losses in tune scans

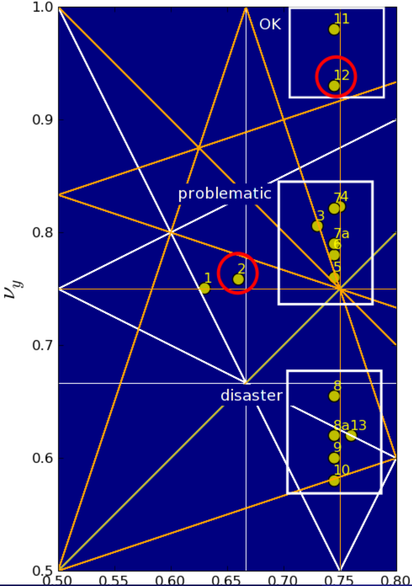


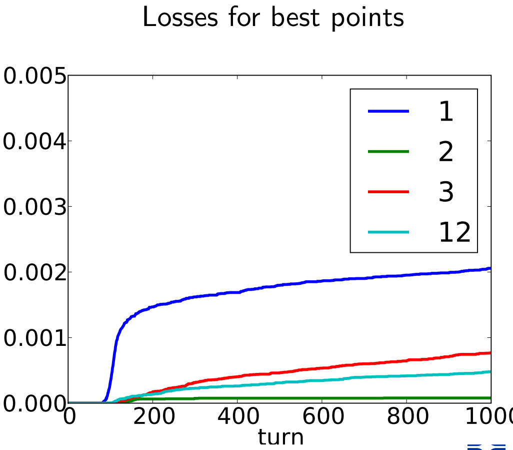
We can also perform detailed studies of individual losses



Mu2e Parameter Scan Summary

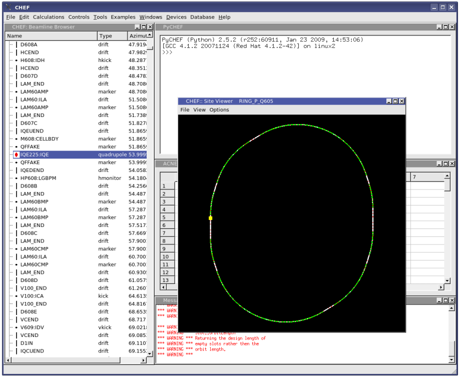
Tune Scan





MI Simulation plans. Available information:

- MI MAD lattice which we can proces with CHEF and Synergia
- MI loss simulation using STRUCT from A. Drozhdin
  - Converter program to import MAD8 format lattice and add apertures for individual elements and beampipes
  - Fortran code implementing apertures
  - Code that implements particle transport through magnets including hardcoded multipole elements with errors
- Access to aperture, alignment, and field measurement data



Our plan

Plan for Synergia MI simulations

- Synergia and CHEF use MAD8 input for the lattice description
- High order multipoles and errors for the magnets will be modeled by adding appropriate multipoles to base values read from the lattice description.
  - Discuss with B. Brown and A. Drozhdin on using more accurate description of individual magnets.
- Individual apertures for different elements will need to be added to Synergia. This is straightforward.
- Model validation: perform comparizons with STRUCT (apertures) and IMPACT (space-charge)
- Model space-charge effects for a single bunch at injection
  - Study emittance dilution and losses
- If desirable, extend simulations to include multi-bunch effects